Atty. Dkt. No.: 054821-0875

U.S. PATENT APPLICATION

for

METHOD FOR DETERMINATION OF THE CHARGE DRAWN BY AN ENERGY STORAGE BATTERY

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CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] Germany Priority Application DE 102 53 051.3, filed November 14, 2002, including the specification, drawings, claims and abstract, is incorporated herein by reference in its entirety.

BACKGROUND

[0002] The present invention relates to a method for determining the charge drawn by an energy storage battery, and for monitoring devices and computer programs for carrying out such a method.

[0003] During operation of batteries (e.g., lead-acid energy storage batteries for use in vehicle starting, lighting, and ignition applications) it is advantageous to determine the instantaneous state of the energy storage battery and to predict a future state with assumed environmental and battery state conditions. In this case, it is also desirable to determine the charge which is drawn in the charging mode.

[0004] It is known for the to measure battery current continuously during the operating life of the energy storage battery for this purpose. The charge flowing into the energy storage battery and the charge drawn from the energy storage battery can be calculated from the converted current, and the state of charge can be determined by balancing these factors.

[0005] It is also known for the change in the state of charge by an energy storage battery to be determined by means of mathematical models, such as equivalent circuits.

[0006] One disadvantage of this method is that the battery current must be measured. Particularly for starter batteries with relatively high starter currents, this is highly complex.

[0007] It would be advantageous to provide an improved method for determination of the charge drawn by an energy storage battery, by means of which the amount of charge drawn by the energy storage battery during the charging mode can be determined as accurately as possible and with little measurement complexity, without measuring the battery current. It would also be advantageous to provide a monitoring device which has computation means for carrying out such a method. It would further be advantageous to provide a computer program to carry out the method described above. It would be advantageous to provide any one or more of these or other advantageous features.

SUMMARY

[0008] An exemplary embodiment relates to a method for determining the charge drawn by an energy storage battery starting from an initial state of charge at the start of the drawing of the charge. The method includes determining the charge drawn as a function of an exponential function with a time constant. The time constant is defined at least as a function of the energy storage battery type and of the temperature of at least one of the battery temperature and the electrolyte temperature.

[0009] Another exemplary embodiment relates to a monitoring device for energy storage batteries. The monitoring device includes a device for measuring battery temperature and a computation device for determining the charge drawn by an energy storage battery starting from an initial state of charge at the start of the drawing of the charge. The computation device is designed to carry out a method comprising determining the charge drawn as a function of an exponential function with a time constant, wherein the time constant is defined at least as a function of the energy storage battery type and of the temperature of at least one of the battery temperature and the electrolyte temperature.

[0010] Another exemplary embodiment relates to a computer program. The computer program includes computer program code designed to carry out a method when the computer program is run using a processor device. The method includes determining the charge drawn by an energy storage battery as a function of an exponential function with a time constant, wherein the time constant is defined at least as a function of the energy storage battery type and of the temperature of at least one of the battery temperature and the electrolyte temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will be explained in more detail in the following text with reference to the attached drawings, in which:

[0012] FIGURE 1 shows a diagram or graph illustrating measured relative accumulated amounts of charge drawn as a function of the initial state of charge, determined using a method according to an exemplary embodiment;

[0013] FIGURE 2 shows a diagram or graph of measured relative accumulated amounts of charge drawn as a function of the initial state of charge, determined using a method according to an exemplary embodiment, with the time constant of the exponential function being corrected by a temperature-dependent correction factor;

[0014] FIGURE 3 shows a diagram or graph of the relative cumulative amounts of charge drawn for an electrolyte temperature of 25°C as a function of the initial state of charge and of the time, using a constant charging voltage for a lead-acid motor vehicle battery; and

[0015] FIGURE 4 shows a diagram or graph of the relative cumulative amounts of charge drawn for an electrolyte temperature of -10°C as a function of the initial state of charge and of the charging time, with a constant charging voltage for a lead-acid motor vehicle battery.

DETAILED DESCRIPTION OF THE PREFERRED AND EXEMPLARY EMBODIMENTS

[0016] An exemplary embodiment relates to a method for determination of the charge drawn by an energy storage battery starting from an initial state of charge at the start of the drawing of the charge.

[0017] According to an exemplary embodiment, the method includes determining the charge drawn as a function of an exponential function with a time constant. The time constant may be defined at least as a function of the energy storage battery type and of the battery or electrolyte temperature.

[0018] This is because experiments have shown that the charge which is drawn from an energy storage battery approaches a defined full state of charge, that is to say the rated capacity, exponentially and asymptotically. The rated capacity for energy storage batteries is already stated by the manufacturer. In this case, it has surprisingly been found that the time constant of the exponential function depends essentially on the energy storage battery type and on the battery or electrolyte temperature. The influence of the state of charge at the start of the drawing of the charge as well as of the mean charging voltage is, in contrast, very much less and need not necessarily be considered. All other influences are completely negligible.

[0019] The measurement complexity for determining the charge drawn is thus reduced to a measurement of the battery or electrolyte temperature, with the measured battery or electrolyte temperature being inserted into a function that is defined for the energy storage battery, in order to calculate the time constant. This function can be determined, for example, experimentally for each energy storage battery.

[0020] The time constant is preferably also defined as a function of the state of charge at the start of the drawing of the charge. It is particularly advantageous for the time constant also to be defined as a function of the charging voltage, of a mean charging voltage, or of a rated charging voltage.

[0021] The time constant can thus be determined by three factors that are multiplied by one another, with the first factor being determined using a function which is dependent on the energy storage battery type and on the charging voltage or on the mean charging voltage or on the rated charging voltage. The second factor is calculated using a function which is dependent on the state of charge at the start of the drawing of the charge. The third factor is calculated using a function which is dependent on the battery or electrolyte temperature.

[0022] The absolute amount of charge drawn by the energy storage battery may, for example, be calculated as a function

$$\Delta Q \approx (1 - e^{-T/\tau})\,(Q_0 - Q_s)$$

with Q_0 being the rated capacity of the energy storage battery and Q_s being the initial charge of the energy storage battery at the start of the drawing of the charge.

[0023] A relative state of charge, with respect to the rated capacity Q_0 of the energy storage battery, can also be calculated as a function

$$Q\,(t)/Q_0 \approx 1 - (1 - Q_s/Q_0)e^{-t/\tau}.$$

[0024] The third factor as a function of the battery or electrolyte temperature may, for example, be a first correction factor τ_T for the time constant τ, which is determined using the formula

$$\tau_T = a^{-(Te - Te,0)/b}$$

where T_e is the electrolyte temperature of the energy storage battery, $T_{e,0}$ is a defined electrolyte nominal temperature, and a and b are constants. This first correction factor τ_T allows the influence of the electrolyte temperature on the charge that is drawn by the energy storage battery to be taken into account. This function is based on the Arrhenius Law, since the limiting physico-chemical reactions are dissolving reactions. For a time constant τ which has been normalized to room temperature of about 20°C,

it has been found to be suitable in this to use a constant a with the value 2 with a tolerance of ±0.5, and a constant b with a value of 10 and a tolerance band of ±1.

[0025] The influence of the state of charge at the start of the drawing of the charge can be expressed by a second correction factor $\tau Q_s/Q_0$ for the time constant τ, whose value range should be between 1 and 1 - Q_s/Q_0. The quotient Q_s/Q_0 is the initial charge Q_s related to the rated capacity Q_0 at the start of the drawing of the charge.

[0026] FIGURE 1 shows a diagram of the relative cumulated amounts of charge drawn

$$\Delta Q(t)/Q_0 = \frac{Q(t) - Q_s}{Q_0}$$

for initial states of charge Q_s/Q_0 of 50% SOC and 70% SOC (SOC = state of charge). The charge that is drawn is plotted as a function of the time of the charging process, with this process being carried out with battery and electrolyte temperatures of 25°C.

[0027] In this case, the charge that was drawn was determined experimentally and, in comparison to this, was calculated using the method according to the exemplary embodiment. The experimentally determined amounts of charge drawn are represented by the curves denoted by circles. The amounts of charge drawn as determined using the method are represented by the curves denoted by lines crossing through.

[0028] As can be seen, the curves determined according to the exemplary embodiment and those determined experimentally for the relative cumulative amount of charge drawn match one another well.

[0029] At the time $t = 0$ the energy storage battery has an initial charge Q_s and an initial state of charge Q_s/Q_0 related to the rated capacity Q_0. The initial state of charge Q_s/Q_0 in the first case is 50% SOC and for the second case is 70% SOC. The remaining 50% or 30% charge, respectively, which can be absorbed as a minimum before reaching the full state of charge with the rated capacity Q_0, is drawn by the

energy storage battery over a period of time in a charging process which takes place approximately exponentially.

[0030] The illustrated relative charge that is drawn $\Delta Q(t)/Q_0$ corresponds to the absolute charge that is drawn, related to the rated capacity Q_0, during the charging process.

[0031] The relative charge that is drawn is, according to the exemplary embodiment, determined proportionally to the formula:

$$\Delta Q/Q_0 \approx (1 - e^{-T/\tau})\,(1 - Q_s/Q_0)$$

where t is the time and τ is a specific time constant. According to an exemplary embodiment, the time constant is a function of the energy storage battery type, of the battery or electrolyte temperature T_e, of the initial state of charge Q_s/Q_0 and of the charging voltage U_L. The charging voltage $U_L(t)$ over time, a mean charging voltage or a rated charging voltage $\bar{U}_{L,0}$, or the like, may be used as the charging voltage.

[0032] The time constant τ is a function of the battery or electrolyte temperature and of the energy storage battery type. The relationship between the optimum time constant τ and the exponential function, on the other hand, is only relatively slightly dependent on the initial state of charge Q_s/Q_0 at the start of the drawing of the charge, and on the charging voltage U_L. The charging voltage U_L may already be available as a specific value for the energy storage battery type, if a function for determination of the time constant τ is determined experimentally as a function of the energy storage battery type.

[0033] The battery or electrolyte temperature that is considered may also, for example, be determined as an instantaneous value measured at the start of the charging process, and may be kept constant for the subsequent charging process. The time constant τ may therefore have a constant value for one charging process. Alternatively, time constant τ may be adapted as a function of time during the charging process.

[0034] FIGURE 2 shows a diagram of the relative charge that is drawn $\Delta Q(t)/Q_0 = Q(t) - Q_s/Q_0$ at an electrolyte temperature of 0°C, and initial states of charge Q_s/Q_0 of 50% SOC and 70% SOC. Once again, the values for the relative charge drawn were determined experimentally and, in comparison to this, were determined by calculation using the method according to the exemplary embodiment. In the illustrated example, the time constant τ was corrected by means of a first correction factor τ_T, which reflects the relationship between the time constant τ and the electrolyte temperature. Since the limiting physico-chemical reactions are dissolving reactions, a correction variable

$$\tau_T = a^{-(Te - Te,0)/b}$$

was defined on the basis of the Arrhenius Law, thus taking account of the influence of the electrolyte temperature on the charge drawn by the energy storage battery. In this case, T_e is the electrolyte temperature, and $T_{e,0}$ is an electrolyte nominal temperature. The constants a and b are variables which are determined experimentally. The constant a should have a value of about 2 with a tolerance band of ±0.5, and the constant b should have a value of about 10 with a tolerance band of ±1.

[0035] As can be seen from FIGURE 2, a time constant τ corrected in this way results in a relatively good match between the calculated relative cumulative charges drawn and the measured relative cumulative charges drawn. The result of the process of determining the charge drawn can be optimized even further by optimization of the constants a and b as a function of the energy storage battery type.

[0036] The dependency of the time constant τ on the relative state of charge Q_s/Q_0 at the start of the drawing of the charge is very small, since the internal resistance R_i of the energy storage battery, which falls during the charging process, is compensated for in accordance with the product $\tau = R_i \times C$ by the rising capacity C of the energy storage battery. When calculating a time constant, the initial relative state of charge Q_s/Q_0 is preferably determined by means of a second correction factor

$$\tau_{Q_s/Q_0} - f(Q_s/Q_0)$$

in which case the second correction factor $\tau Q_s/Q_0$ should assume a value between 1 and $(1 - Q_s/Q_0)$.

[0037] The time constant τ can thus be determined using the relationship:

$\tau \approx R_{i0}$(energy storage battery type, U_L)• τ_{Qs}/Q_0•τ_T = τ_{RT0}(energy storage battery type, U_L)•$f(Q_s/Q_u)$•$f(T_e)$

where τ_{RT0} is a time constant at room temperature, which is dependent only on the energy storage battery type and on the charging voltage U_L. This component τ_{RT0} of a time constant τ can be determined experimentally for energy storage batteries of one type and for vehicles from one manufacturer with respect to the normal charging voltage U_L, so that only a temperature measurement is required in order to determine the charge that is drawn.

[0038] FIGURE 3 shows a diagram of the relative cumulative charge drawn $\Delta Q(t)/Q_0$ as a function of the initial relative state of charge Q_s/Q_0 at the start of the drawing of the charge, and the charging time t for a constant charging voltage of 14.2 V and an electrolyte temperature of 10°C, using the example of a lead-acid motor vehicle battery. This clearly shows that the charge drawn has an exponential profile. The exponential curves which are adjacent to one another for different initial states of charge have a high degree of linearity over a wide range of an initial relative state of charge Q_s/Q_0 from about 0% to 0.7%. This means that the influence of the initial relative state of charge on the curve profile is low.

[0039] FIGURE 4 shows the relative cumulative charge drawn $\Delta Q(t)/Q_0$ as a function of the initial relative state of charge Q_s/Q_0 at the start of the drawing of the charge, and the time t for a constant charging voltage of 14.2 V and an electrolyte temperature of 25°C. In comparison to the curve profile in FIGURE 3, this clearly shows that the profile of the charge drawn varies to a major extent when the electrolyte temperature T_e changes. However, once again, the curve profile follows an exponential function.

[0040] According to an exemplary embodiment, a monitoring device for energy storage batteries is provided which includes a battery temperature measurement unit and a computation device or means for determining the charge drawn by the energy storage battery on the basis of the method mentioned above. The computation device may, for example, be in the form of a computer program which is run on a processor or processing device (e.g., a microprocessor), for example, a central vehicle computer in a motor vehicle.

[0041] According to another exemplary embodiment, a computer program is provided that includes program code for carrying out the method mentioned above. The program code is designed or configured to carry out the method when the computer program is run on a processor or processing device (e.g., a microprocessor), for example, a central vehicle computer in a motor vehicle. The computer program may be stored on a data storage medium (e.g., a disk drive, a CD, a floppy disk, etc.).

[0042] It is important to note that the preferred and other exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible (e.g., variations in values of parameters, etc.) without materially departing from the novel teachings and advantages of the subject matter recited herein. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the preferred and other exemplary embodiments without departing from the scope of the present inventions.